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Bioenvironmental Engineer's Guide to TVA-1000B Toxic Vapor Analyzer

Capt Jason Flory

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14. ABSTRACT
The Thermo Scientific Toxic Vapor Analyzer (TVA)-1000B is an intrinsically safe direct reading portable monitor that uses either a flame ionization detector, a photoionization detector, or both simultaneously to provide real-time measurements of organic and some inorganic vapor concentrations in air. This field guide provides operators and incident commanders the basic concepts for effective use of the TVA-1000B, including principles of operation and supplies required.

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Chapter 1. Introduction

This guide is intended to meet the needs of users throughout the Air Force Bioenvironmental Engineering community. To achieve this goal, your input is indispensable. Please contact the Environmental Safety and Occupational Health (ESOH) Service Center at 888-232-ESOH, DSN 798-3764, or email mailto:esoh.service. center@wpafb.af.mil to provide your valuable insight into how this guide can be improved through changes or additions to its content.

This field guide provides operators and incident commanders the basic concepts for effective use of the Thermo Scientific Toxic Vapor Analyzer (TVA)-1000B, including principles of operation and supplies required. Chapter 2 describes the principles and methods by which the TVA-1000B is operated, as well as capabilities and limitations of the instrument. Chapter 3 discusses basic user maintenance and decontamination. More detailed information on the instrument, including advanced features, can be found in the manufacturer's instruction manual. Additionally, detailed "how-to" instructions on using the instrument can be found in the U.S. Air Force School of Aerospace Medicine's (USAFSAM) "TVA-1000B Checklist" on the ESOH Service Center website; the website also includes instructional videos that demonstrate use and care of the TVA-1000B.

Chapter 2. Operation

The TVA-1000B is an intrinsically safe direct reading portable monitor that uses either a flame ionization detector (FID), a photoionization detector (PID), or both simultaneously to provide real-time measurements of organic and some inorganic vapor concentrations in air. The vapor concentration may be read immediately on either of two displays – one mounted directly on the hand-held sample probe and the other on the instrument sidepack. The TVA-1000B shows direct reading results in parts per million (ppm), parts per billion (ppb), or percent concentration (%) [1].

a. Capabilities: The primary purpose of the TVA-1000B is to provide a quick screening tool for detection of a wide variety of toxic industrial chemicals, while at the same time giving a good approximation of the quantity of contaminant present. The TVA-1000B can also be used to detect and monitor chemical warfare agents (CWAs). It was tested against three CWAs by Longworth et al. [2]: tabun, sarin, and sulfur mustard. The data are presented below in a summary matrix in Table 1 as a quick reference guide to the TVA-1000B's capability for detecting CWAs. All data summarized in Table 1 focused predominantly on the ability of the TVA-1000B to respond to CWAs in air and at relatively high concentration levels.

Table 1. Confirmed TVA-1000B CWA Capabilities Matrix [2]

Sample Media	*CWA*	*FID*	*PID*
Vapor	tabun	Responded	Responded
	sarin	Responded	No Response
	sulfur mustard	No Response	Responded

Hydrogen cyanide can also be detected by an FID, but not by a PID [3]. The PID can detect a range of organic chemicals and some inorganic chemicals including aromatics, unsaturated chlorinated hydrocarbons, aldehydes, ketones, ethylene oxide, hydrogen sulfide, and glycol ether solvents. The FID is insensitive to most inorganic compounds, such as water, nitrogen, and oxygen, and its response to carbon monoxide and carbon dioxide is negligible, making it useful for air analysis [4]. The instrument is certified to be intrinsically safe [1].

b. Limitations: The TVA-1000B does not have the capability to monitor or detect biological warfare agents or radiological hazards. It does not provide identification of unknown chemical compounds. It can be used to monitor known or suspected hazardous chemicals; however, it is only possible to use a PID quantitatively if only one chemical is present in air or if a mixture of chemicals is present and each chemical has the same ionization potential (IP), since PID sensitivity is dependent on the compound being detected and its IP (see below, Photoionization Detector). Furthermore, FID response does not represent the concentrations of individual organic compounds, but rather an estimate of the combined concentration of volatile organic compounds present [4]. As noted in Appendix A, the measurement accuracy of the TVA-1000B is approximately ±25%. Chlorine gas is an important chemical that cannot be detected by the TVA-1000B [3]. These limitations are summarized in Table 2.

Table 2. Limitations of TVA-1000B

Capability	*TVA-1000B*
Biological warfare agent detection	no
Radiological hazard detection	no
Unknown compound identification	no
Quantification of individual compounds in mixture	no
Measurement accuracy	±25%
Chlorine gas detection	no

Continued exposure to vapors can significantly degrade the overall performance of the detectors; therefore, routine cleaning is necessary as described in Table 3. The ultraviolet lamp used by the PID to ionize vapor samples for detection becomes contaminated easily by dust, dirt, moisture, and residue during use; it should not be used in areas of high vapor concentration (published dynamic range of PID: 0-2000 ppm). The FID also requires cleaning. Thorough cleaning is required to maintain “factory level” performance [2]. The TVA-1000B does not operate properly at temperatures below 32°F (freezing). The FID also requires about 16% oxygen to support its flame, which could be a limiting factor in confined spaces or when analyzing vapor from a bag sample [1].

Table 3. Detector Sensitivity [1]

Detector	*Zero Counts*	*Acceptable Detector Sensitivity*
FID	<5000	160-260 counts/ppm Methane
PID (10.6-eV lamp)	2000-8000	3500-6000 counts/ppm Isobutylene
PID (11.8-eV lamp)	2000-20,000	300-900 counts/ppm Isobutylene

c. Flame Ionization Detector: The FID mode is used to detect most organic compounds and can be used to detect gaseous hydrocarbons in depressions or confined spaces. The FID uses a flame produced by the combustion of hydrogen and oxygen (air) to ionize volatile organic compounds. The ions are collected on an electrode, which produces a current proportional to the concentration of the hydrocarbons exposed to the flame.

(1) Benefits of flame ionization detection:
- Wide dynamic and linear range
- High sensitivity to hydrocarbon vapors (including methane)
- Very stable and repeatable response
- Virtually unaffected by ambient levels of carbon monoxide, carbon dioxide, and water vapor

d. Photoionization Detector: In the PID mode, the instrument uses an ultraviolet lamp and an ionization chamber to ionize chemical compounds. As in FID mode, the resulting ions are attracted to an electrode, which produces a current proportional to the concentration of the ionized compound. This process results in direct measurement of airborne chemical compounds at ppb levels (published minimum detectable level: 100 ppb of benzene). The PID is sensitive to compounds with double or triple bonds, such as aromatic and chlorinated compounds, and can measure some inorganic compounds that the FID does not detect, including ammonia, carbon disulfide, and hydrogen sulfide [1].

The PID detection capability depends upon the compound's IP, meaning the energy required to remove an electron from the compound. If the lamp energy is greater than the IP of the compound, the PID will detect it. In general, larger molecules with more double or triple bonds need less energy to be ionized [5]. The standard lamp in the TVA-1000B produces 10.6 eV. Other lamps produce 9.6 eV, 10.0 eV, or 11.8 eV and can be purchased separately. The non-standard lamps permit the user to detect or rule out many compounds not ionized by the standard lamp. Refer to Appendix B to determine which lamps are used for particular common chemicals.

(1) Benefits of photoionization detection:
- High sensitivity to aromatics, unsaturated hydrocarbons, and chlorinated hydrocarbons
- Ability to measure some inorganic gases
- Very simple operation
- No support gases required
- Non-destructive detector allows sample to be recovered

e. Dual Detectors: Since both detectors may be displayed simultaneously, the relative response of the two detectors may give an indication of the identity of the compound being measured. For instance, the PID does not respond to methane, but the FID responds to it very well. A high FID reading with virtually no PID response might indicate the presence of methane [1]. Likewise, a PID responds very well to some inorganic gases that an FID cannot detect. A high PID reading with no FID reading might suggest the presence of an inorganic compound, such as ammonia. With readings from both detectors readily available, the TVA-1000B can help a user make decisions about the type of compound present and which detector reading to use when making a concentration estimate.

f. Instrument Functions: This analyzer functions in any of four modes:

(1) RUN
(2) SETUP
(3) INFO
(4) PC LINK/MEMORY

In RUN mode, the instrument automatically displays measured values in units of ppm, ppb, or %. In SETUP mode, operational parameters can be entered or selected, such as calibration values. In INFO mode, operational parameters entered or selected in SETUP mode can be reviewed, as well as instrument serial number, battery status, etc. Each of the four modes is explained in detail in the user manual.

g. Using the Instrument: While operating this instrument in the field, the TVA-1000B is normally carried at the operator's side, using the shoulder strap. With the pump on, detector(s) on, and the unit warmed up, monitor the area of concern. As soon as the instrument analyzes a sample, the probe displays concentration of the vapor. The display on the sidepack duplicates the vapor concentration on the probe display. Toggle the display between detector types by pressing the DET button on the probe. Pressing the lamp button backlights the LCD display.

h. Measurements and Calibration: The FID is calibrated with *methane*, and the PID is calibrated with *isobutylene,* but both detectors respond to different compounds with differing levels of sensitivity. To correct for differences in sensitivity and provide more accurate concentration measurements, *response factors* must be applied to the instrument's readings. If the contaminant being measured is known, the TVA-1000B can be programmed to apply a response factor automatically via its "calibration" menu, eliminating the need for the user to perform a correction calculation for each measurement. Users can choose from up to nine user-defined response factors, or use the default factor of 1.00. Each response factor can be assigned a nine-character alphanumeric name. A *response factor multiplier* is defined as follows [1]:

$$Response\ Factor = \frac{\text{Actual Concentration}}{\text{Measured Concentration}}$$

Response factor multipliers for many chemicals at several concentration levels are listed in Appendix C.

Detector counts are the raw, unscaled detector output values associated with a gas measurement performed by the FID or the PID. Detector counts are *not* the numbers displayed on the TVA-1000B in "RUN" mode. The zero gas and span gas detector count values are stored each time the TVA-1000B is calibrated; these values are used as reference points for calculating the concentration values displayed by the instrument [1].

The detector counts can also be used for indicating successful calibration and to calculate instrument sensitivity. The zero gas count is what is expected when the zero gas is applied to the detector. Zero gas, a.k.a. zero air, is air that has been verified to contain less than 1 ppm total hydrocarbons. The TVA-1000B is "zeroed" when it measures its own response to zero gas so it can automatically subtract that response as "background" when measuring contaminant levels. Similarly, the span gas count corresponds to the concentration of the specific span gas used to test the instrument. Span gas (methane or isobutylene at a known concentration) is used by the TVA-1000B as a point of reference that it compares against future measurements to determine the concentration of contaminants in air. To check instrument sensitivity, subtract the zero gas count from the span gas count, then divide by the span gas concentration (see Table 3 [1]).

Example: A TVA-1000B FID is calibrated with zero air and 100-ppm methane span gas. Counts observed for the zero are 2895, and counts observed for the span are 27395. Sensitivity is thus 245 counts/ppm [(27395-2895)/100 ppm]. Since both FID values (2895 zero counts and 245 counts/ppm detector sensitivity) are within the acceptable range per Table 3, the calibration is a good calibration. A bad calibration is determined by high zero counts or detector sensitivity falling outside ranges specified in Table 3. A bad calibration can often be attributed to poor calibration gases, contaminated sampling accessories, a faulty detector capsule, or failure to follow proper calibration procedure [1].

i. Sequence of Operation (Figure 1)

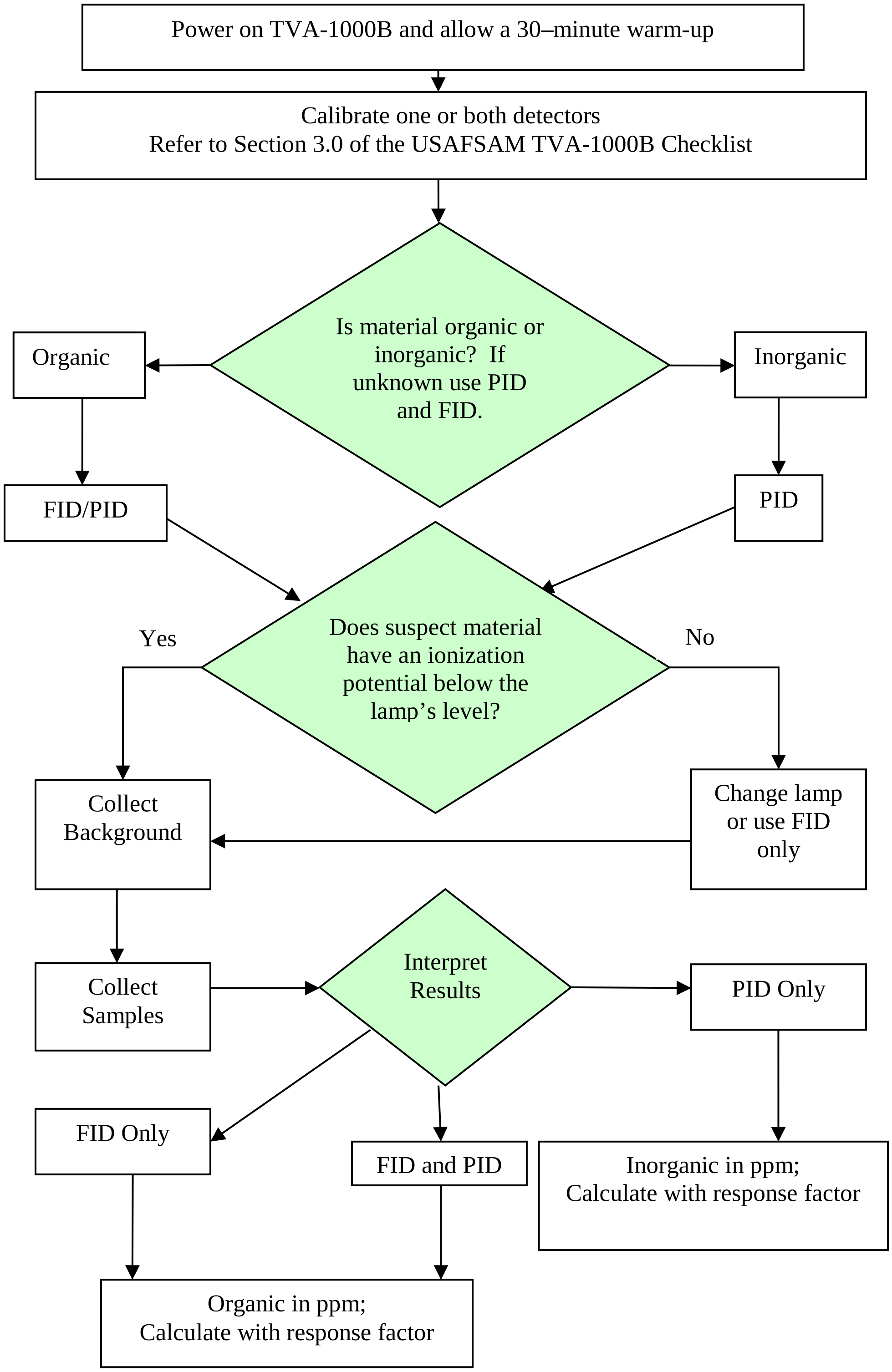

Figure 1. Logical Sequence of Operation

Chapter 3. Maintenance

From time to time, several components of the TVA-1000B must be removed and replaced. Some components may be replaced as normal maintenance functions performed by operating personnel. Other components, however, should be replaced only by personnel thoroughly trained and familiar with the analyzer instrument and its applications. The operations that follow are demonstrated in video guides that can be found on the ESOH Service Center website.

a. Accessories and Supplies: The components that may be maintained or replaced by operating personnel as part of normal operation are listed in Table 4. All descriptions of frequency (e.g., "periodically," "frequently") are from manufacturers' guidance in the user manual. Actual frequency of operations will depend on how often a particular Bioenvironmental Engineering flight uses the TVA-1000B. For example, if the instrument is only used three times per year, it would not make sense to clean the PID cartridge on a weekly basis. Determine a maintenance schedule that fits your pattern of use. Consider cleaning the instrument's components when user calibration results do not meet criteria. For more help, contact the USAFSAM ESOH Service Center for an individual consultation.

Table 4. TVA-1000B Parts and Accessories Replaceable by Operating Personnel [1]

Item	*Action*
Battery	Battery can be charged in or out of the instrument.
Hydrogen Tank	Remove the tank to refill.
PID Cartridge	Remove and clean frequently. Replace when needed.
FID Cartridge	Remove and clean frequently. Replace when needed.
Optional Close Area Sampler	Replace if probe tip is clogged or damaged.
Filter Cups (part of Close Area Sampler)	Clean/replace frequently (in the side pack assembly). Refer to User's Manual.
Water Trap Probe (part of Close Area Sampler)	Replace membrane if worn or damaged. Refer to User's Manual.
Optional Charcoal Filter Adapter (in sampling assembly)	Replace charcoal frequently. Refer to User's Manual.
Sample Line Tubing	Replace when dirty.
Sample Line Fitting	Replace if damaged.
FID End Cap and Flame Arrestor	Remove and clean frequently. Replace when required.
FID Cavity	Clean periodically.
PID Cavity	Clean periodically.

(1) Battery and battery charger

WARNING: *Do not remove or charge batteries in any area classified as hazardous due to the potential presence of flammable gases or vapors* [1].

The nickel cadmium battery, supplied with the unit, lasts for a minimum of 8 hours of continuous use at 20°C. Extreme heat or cold and/or use of the backlight will shorten operational time [1].

The battery does not need to be removed from the TVA-1000B for charging. Simply plug the output of the charger into the mating connector marked “CHRG” on the instrument. Then insert the charger plug into the appropriate wall outlet. A green power indicator is on when the charger is operating. A yellow indicator is activated when the charger is connected to the instrument and the instrument is on. Normal charge time for a fully discharged battery is approximately 16 hours, or 2 hours of charge for every hour of use. To charge the battery outside of the unit, use the adapter supplied in the accessory kit [1].

Do not leave the battery on charge for greater than 96 hours. When removing the battery from the TVA-1000B for charging or swapping with a spare battery, turn the instrument off. Using the special tool supplied with the accessory kit, unscrew the screw on the battery compartment cover on the rear of the instrument and remove the battery cover. The battery pack fits snugly into the TVA-1000B, so use care in removing the battery pack and its internal connector. When removing the battery pack, note the location of the battery connector. When reinserting the battery pack into the instrument, be sure to push the connector into the same location so it does not interfere with placement of the battery pack [1].

(2) Hydrogen tank: TVA-1000B FID instruments are supplied with an 85-cc hydrogen gas tank. This tank, which must not be filled to more than 2,200 psi, will provide up to 8 hours of operation when fully charged. The tank has an integrally mounted pressure gauge that can be easily read when the tank is in or out of the instrument. When transporting the instrument, remove the hydrogen tank and place it in its normal location in the carrying case. Install the tank in the instrument by inserting it into the receptacle on the side of the TVA-1000B and tightening until the rubber tank boot is flush with the instrument sidepack and a slight resistance is felt. **NOTE: All hydrogen fittings are left-hand threaded – do not overtighten** [1]**.**

(a) Hydrogen tank refilling procedure: A safe refill operation is one with no hydrogen leaks. Before any valves are opened, use a non-sparking wrench to firmly tighten connections to the hydrogen supply tank and the tank fill adapter. If escaping hydrogen is heard during the refilling operation, close all valves and correct the leak before proceeding. The connections can be leak tested with soapy water. Use prepurified zero grade hydrogen (certified total hydrocarbons as methane < 0.5 ppm recommended). **NOTE: All hydrogen fittings are left-hand threaded – do not overtighten** [1]**.**

b. Servicing the PID Cartridge: To service the PID cartridge, use the following procedure:

(1) Turn the instrument off.
(2) Using the special spanner wrench provided with the instrument tool kit, unscrew the blue cap holding the PID cartridge in place.
(3) Screw the special extractor tool provided with the accessory kit into the off-center hole in the cartridge. (Do not exceed three full turns.)
(4) Remove the cartridge by pulling on the extractor. Unscrew the extractor from the cartridge. Clean or replace the cartridge.
(5) To insert a new cartridge, reverse the procedure. Note that the standard 10.6-eV PID cartridge is marked with a blue band. Other energy level lamps are marked with different colors (not red).

For normal, periodic cleaning of a PID lamp window (other than an 11.8-eV lamp), use the following procedure. The manufacturer's manual contains detailed information about care and use of 11.8-eV lamps in an appendix labeled "MI 611-183."

(1) Remove the cartridge from the instrument as described above.
(2) Clean the lamp window using a cotton swab with isopropyl alcohol.
(3) Using a heat gun, dry the cartridge for about 60 seconds to evaporate the alcohol. Reinsert the cartridge into the instrument.
(4) Screw in the blue PID detector cap, using the special spanner wrench supplied with the tool kit. Do not overtighten the cap.

To clean a PID lamp window with the optional PID lamp cleaning kit, use the following procedure:

(1) Remove the cartridge from the instrument as described above.
(2) Clean the window of the lamp, using the materials supplied with the optional PID lamp cleaning kit. Follow the instructions included with the cleaning kit, being careful never to touch the window with your fingers.
(3) When the cartridge is dry (dry at 40°C to 55°C for 1 hour), screw the extractor into the cartridge and reinsert it into the instrument.
(4) Screw in the blue PID detector cap, using the special spanner wrench supplied with the tool kit. Do not overtighten the cap.

c. Servicing the FID Cartridge: To remove the FID cartridge, use the following procedure:

(1) Close the hydrogen supply valve on the side of the instrument. Turn the instrument off.
(2) Using the special spanner wrench provided with the instrument tool kit, unscrew the red cap holding the FID cartridge in place.
(3) Screw the special extractor tool provided with the accessory kit into the off-center hole in the cartridge.
(4) Remove the cartridge by pulling on the extractor. Unscrew the extractor from the cartridge. Clean or replace the cartridge.
(5) To insert a new cartridge, reverse the procedure. Note that a FID cartridge is marked with a red band.

To clean a FID cartridge, use a cotton swab and some isopropyl alcohol. Dip the swab into the isopropyl alcohol and insert it into the center of the cartridge. Swab the surface until clean and discard the swab. Take care not to touch the igniter coil, which is located close to the end of the capsule opposite the threaded hole used to remove the capsule. Then dry the cartridge (if available, manufacturer recommends drying in an oven at 45°C to 55°C [113°F to 131°F]) for one hour. When dry, re-insert the cartridge into the instrument, reversing the removal procedure. Do not overtighten cap.

d. Cleaning the FID Detector Cap: To clean the FID detector end cap, use the following procedure:

(1) Close the hydrogen supply valve on the side of the instrument and turn off the power.
(2) Using the special spanner wrench provided with the tool kit, unscrew and remove the FID red detector cap.
(3) Clean the cap using isopropyl alcohol followed with a deionized or distilled water rinse. Blow out carefully with compressed dry air.
(4) Replace the cap.

e. Replacing the Flame Arrestor: The flame arrestor, located in the center of the red FID end cap, can be either cleaned or replaced. To replace the flame arrestor, use the following procedure:

(1) Close the hydrogen supply valve on the side of the instrument and turn off the power.
(2) Using the special spanner wrench provided with the tool kit, unscrew and remove the FID red detector cap.
(3) Remove the spring.
(4) Place the detector cap on a flat surface, face up.
(5) Place a screwdriver through the center hole of the end cap, resting on the flame arrestor.
(6) Strike the end of the screwdriver with a hammer to drive the old flame arrestor out of the end cap.
(7) Remove the old flame arrestor.
(8) Turn the end cap over so the red outer surface lies flat and the gray surface faces up.
(9) Place the new flame arrestor in the center hole.
(10) Place a screwdriver on the newly installed flame arrestor.
(11) Strike the end of the screwdriver with a hammer to secure the new flame arrestor in place.
(12) Replace the spring.
(13) Replace the detector cap on the unit.

f. Cleaning the FID and PID Detector Cavities

(1) Close the hydrogen supply valve on the side of the instrument. Turn the instrument off.
(2) Using the special spanner wrench provided with the tool kit, unscrew the cap holding the respective detector cap.
(3) Using the special extractor tool provided with the tool kit, screw the extractor into the cartridge.
(4) Remove the cartridge by pulling on the extractor. Unscrew the extractor from the cartridge.

(5) Carefully clean the inside of the detector cavity using a cotton swab and isopropyl alcohol. Be sure to clean the high-voltage contacts along the side of the cavity. Be especially careful around the detector signal collector probe at the rear of the cavity (and the thermocouple probe in the FID).
(6) Dry the inside of the cavity using a low heat gun.
(7) Insert the cartridges into their respective cavities by reversing the procedure. Note that the cartridges must be rotated to properly locate the key tabs.

g. Decontamination Procedures: The TVA-1000B can be decontaminated by wiping the exterior with a moist towel. Do not decontaminate the TVA-1000B by submerging it in water. If the TVA-1000B is accidentally contaminated by drawing a liquid sample into the probe head, it is recommended to call the manufacturer, Thermo Fisher Scientific, toll free at 1-866-282-0430. They will be able to better determine internal decontamination procedures based on the chemical that may have been drawn inside the instrument [ESOH Service Center website: https://hpws.afrl.af.mil/dhp/OE/ESOHSC/].

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Appendix A
Specifications and Power Requirements

Item	Specification
Weight	Approximately 13 pounds
Size	13.5 x 10.3 x 3.2 inches
Temperature Range	0°C to 40°C (32°F to 104°F)
Humidity Range	FID: 20 to 95% PID: 20 to 70% non-condensing
Power Source	Rechargeable NiCd Battery
Battery Operating Time	8 hours
Minimum Detectable Level	PID Instrument - 100 ppb of benzene FID Instrument - 300 ppb of hexane (**See Note)**
Accuracy	PID: ±25% of reading or ±2.5 ppm, whichever is greater, from 0.5 to 500 ppm. FID: ±25% of reading or ±2.5 ppm, whichever is greater, from 1.0 to 10,000 ppm.
Repeatability	PID Instrument: ±1% at 100 ppm of isobutylene FID Instrument: ±2% at 100 ppm of methane
Dynamic Range	PID Instrument: 0.5 to 2,000 ppm of isobutylene FID Instrument: 1.0 to 50,000 ppm of methane
Linear Range	PID Instrument: 0.5 to 500 ppm of isobutylene FID Instrument: 1.0 to 10,000 ppm of methane
Response Time using close area sampler	PID Instrument: Less than 3.5 seconds for 90% of final value FID Instrument: Less than 3.5 seconds for 90% of final value
Recovery Time using close area sampler	PID Instrument: Less than 5.0 seconds to return to 10% of baseline FID Instrument: Less than 5.0 seconds to return to 10% of baseline
Sample Flow Rate	1 L/min, at sample probe inlet
PID Lamp Life	Greater than 2,000 hours for 10.6-eV lamp with normal cleaning and less than 100 hours for 11.8 eV with normal cleaning.
FID Life	Greater than 2,000 hours with normal cleaning
Audio Output Level	Greater than 75 dB at 3 feet
Gas Cylinder Capacity	Pressure - 2,200 psi at 77°F maximum Empty - 85 cc (5.19 in^3)
Hydrogen Supply Operating Time	Greater than 8 hours of continuous operation, starting from a cylinder charged up to 2,200 psi

Note: Benzene and hexane were historically used as calibration gases, which is why they are included here. Manufacturer has stated that chemicals with similar response factors will have the same minimum detectable level; one with a response factor double of benzene or hexane would have approximately double the minimum detectable level.

Appendix B
List of Common Chemicals and Ionization Potentials

Chemical	IP (eV)	Chemical	IP (eV)	Chemical	IP (eV)
A		2-Butanone (MEK)	9.54	1-Chlorobutane	10.67
2-Amino pyridine	8.00	3-Bromopropene	9.70	1-Chloropropane	10.82
Acetaldehyde	10.21	3-Butene nitrile	10.39	2-Chloro-2-methylpropane	10.61
Acetamide	9.77	Benzaldehyde	9.53	2-Chlorobutane	10.65
Acetic acid	10.69	Benzene	9.25	2-Chloropropane	10.78
Acetic anhydride	10.00	Benzenethiol	8.33	2-Chlorothiophene	8.68
Acetone	9.69	Benzonitrile	9.71	3-Chloropropene	10.04
Acetonitrile	12.20	Benzotrifluoride	9.68	Camphor	8.76
Acetophenone	9.27	Biphenyl	8.27	Carbon dioxide	13.79
Acetyl bromide	10.55	Boron oxide	13.50	Carbon disulfide	10.07
Acetyl chloride	11.02	Boron trifluoride	15.56	Carbon monoxide	14.01
Acetylene	11.41	Bromine	10.54	Carbon tetrachloride	11.47
Acrolein	10.10	Bromobenzene	8.98	Chlorine	11.48
Acrylamide	9.50	Bromochloromethane	10.77	Chlorine dioxide	10.36
Acrylonitrile	10.91	Bromoform	10.48	Chlorine trifluoride	12.65
Allyl alcohol	9.67	Butane	10.63	Chloroacetaldehyde	10.61
Allyl chloride	9.90	Butyl mercaptan	9.15	Chloroacetophenone	9.44
Ammonia	10.20	cis-2-Butene	9.13	Chlorobenzene	9.07
Aniline	7.70	m-Bromotoluene	8.81	Chlorobromomethane	10.77
Anisidine	7.44	n-Butyl acetate	10.01	Chlorofluoromethane (Freon 22)	12.45
Anisole	8.22	n-Butyl alcohol	10.04	Chloroform	11.37
Arsine	9.89	n-Butyl amine	8.71	Chlorotrifluoromethane (Freon 13)	12.91
B		n-Butyl benzene	8.69	Chrysene	7.59
1,3-Butadiene (butadiene)	9.07	n-Butyl formate	10.50	Cresol	8.14
1-Bromo-2-chloroethane	10.63	n-Butyraldehyde	9.86	Crotonaldehyde	9.73
1-Bromo-2-methylpropane	10.09	n-Butyric acid	10.16	Cumene (isopropyl benzene)	8.75
1-Bromo-4-fluorobenzene	8.99	n-Butyronitrile	11.67	Cyanogen	13.80
1-Bromobutane	10.13	o-Bromotoluene	8.79	Cyclohexane	9.80
1-Bromopentane	10.10	p-Bromotoluene	8.67	Cyclohexanol	9.75
1-Bromopropane	10.18	p-tert-Butyltoluene	8.28	Cyclohexanone	9.14
1-Bromopropene	9.30	s-Butyl amine	8.70	Cyclohexene	8.95
1-Butanethiol	9.14	s-Butyl benzene	8.68	Cyclo-octatetraene	7.99
1-Butene	9.58	sec-Butyl acetate	9.91	Cyclopentadiene	8.56
1-Butyne	10.18	t-Butyl amine	8.64	Cyclopentane	10.53
2,3-Butadione	9.23	t-Butyl benzene	8.68	Cyclopentanone	9.26
2-Bromo-2-methylpropane	9.89	trans-2-Butene	9.13	Cyclopentene	9.01
2-Bromobutane	9.98	**C**		Cyclopropane	10.06
2-Bromopropane	10.08	1-Chloro-2-methylpropane	10.66	m-Chlorotoluene	8.83
2-Bromothiophene	8.63	1-Chloro-3-fluorobenzene	9.21	o-Chlorotoluene	8.83

Chemical	IP (eV)	Chemical	IP (eV)	Chemical	IP (eV)
p-Chlorotoluene	8.70	Dichloromethane	11.35	Ethanolamine	8.96
D		Diethoxymethane	9.70	Ethene	10.52
1,1-Dibromoethane	10.19	Diethyl amine	8.01	Ethyl acetate	10.11
1,1-Dichloroethane	11.12	Diethyl ether	9.53	Ethyl alcohol	10.48
1,1-Dimethoxyethane	9.65	Diethyl ketone	9.32	Ethyl amine	8.86
1,1-Dimethylhydrazine	7.28	Diethyl sulfide	8.43	Ethyl benzene	8.76
1,2-Dibromoethene	9.45	Diethyl sulfite	9.68	Ethyl bromide	10.29
1,2-Dichloro-1,1,2,2-tetrafluoroethane (Freon 114)	12.20	Difluorodibromomethane	11.07	Ethyl chloride (chloroethane)	10.98
1,2-Dichloroethane	11.12	Dihydropyran	8.34	Ethyl disulfide	8.27
1,2-Dichloropropane	10.87	Diiodomethane	9.34	Ethyl ether	9.51
1,3-Dibromopropane	10.07	Diisopropylamine	7.73	Ethyl formate	10.61
1,3-Dichloropropane	10.85	Dimethoxymethane (methylal)	10.00	Ethyl iodide	9.33
2,2-Dimethyl butane	10.06	Dimethyl amine	8.24	Ethyl isothiocyanate	9.14
2,2-Dimethyl propane	10.35	Dimethyl ether	10.00	Ethyl mercaptan	9.29
2,3-Dichloropropene	9.82	Dimethyl sulfide	8.69	Ethyl methyl sulfide	8.55
2,3-Dimethyl butane	10.02	Dimethylaniline	7.13	Ethyl nitrate	11.22
3,3-Dimethyl butanone	9.17	Dimethylformamide	9.18	Ethyl propionate	10.00
cis-Dichloroethene	9.65	Dimethylphthalate	9.64	Ethyl thiocyanate	9.89
Decaborane	9.88	Dinitrobenzene	10.71	Ethylene chlorohydrin	10.52
Diazomethane	9.00	Dioxane	9.19	Ethylene diamine	8.60
Diborane	12.00	Diphenyl	7.95	Ethylene dibromide	10.37
Dibromochloromethane	10.59	Dipropyl amine	7.84	Ethylene dichloride	11.05
Dibromodifluoromethane	11.07	Dipropyl sulfide	8.30	Ethylene oxide	10.57
Dibromomethane	10.49	Durene	8.03	Ethylenelmine	9.20
Dibutylamine	7.69	m-Dichlorobenzene	9.12	Ethynylbenzene	8.82
Dichlorodifluoromethane (Freon 12)	12.31	n,n-Diethyl acetamide	8.60	**F**	
Dichlorofluoromethane	12.39	n,n-Diethyl formamide	8.89	2-Furaldehyde	9.21
Dichloromethane	11.35	n,n-Dimethyl acetamide	8.81	Fluorine	15.70
Diethoxymethane	9.70	n,n-Dimethyl formamide	9.12	Fluorobenzene	9.20
Diazomethane	9.00	o-Dichlorobenzene	9.06	Formaldehyde	10.87
Diborane	12.00	p-Dichlorobenzene	8.95	Formamide	10.25
Dibromochloromethane	10.59	p-Dioxane	9.13	Formic acid	11.05
Dibromodifluoromethane	11.07	trans-Dichloroethene	9.66	Freon 11 (trichlorofluoromethane)	11.77
Dibromomethane	10.49	**E**		Freon 112 (1,1,2,2-tetrachloro-1,2-difluoroethane)	11.30
Dibutylamine	7.69	Epichlorohydrin	10.20	Freon 113 (1,1,2-trichloro-1,2,2-trifluororethane)	11.78
Dichlorodifluoromethane (Freon 12)	12.31	Ethane	11.65	Freon 114 (1,2-dichloro-1,1,2,2-tetrafluoroethane)	12.20
Dichlorofluoromethane	12.39	Ethanethiol (ethyl mercaptan)	9.29	Freon 12 (dichlorodifluoromethane)	12.31

Chemical	IP (eV)	Chemical	IP (eV)	Chemical	IP (eV)
Freon 13 (chlorotrifluoromethane)	12.91	Isobutyric acid	10.02	Methyl butyl ketone	9.34
Freon 22 (chlorofluoromethane)	12.45	Isopentane	10.32	Methyl butyrate	10.07
Furan	8.89	Isophorone	9.07	Methyl cellosolve	9.60
Furfural	9.21	Isoprene	8.85	Methyl chloride	11.28
m-Fluorotoluene	8.92	Isopropyl acetate	9.99	Methyl chloroform (1,1,1-trichloroethane)	11.00
o-Fluorophenol	8.66	Isopropyl alcohol	10.16	Methyl disulfide	8.46
o-Fluorotoluene	8.92	Isopropyl amine	8.72	Methyl ethyl ketone	9.53
p-Fluorotoluene	8.79	Isopropyl benzene	8.69	Methyl formate	10.82
H		Isopropyl ether	9.20	Methyl iodide	9.54
1-Hexene	9.46	Isovaleraldehyde	9.71	Methyl isobutyl ketone	9.30
2-Heptanone	9.33	m-Iodotoluene	8.61	Methyl isobutyrate	9.98
2-Hexanone	9.35	o-Iodotoluene	8.62	Methyl isocyanate	10.67
Heptane	10.08	p-Iodotoluene	8.50	Methyl isopropyl ketone	9.32
Hexachloroethane	11.10	**K**		Methyl isothiocyanate	9.25
Hexane	10.18	Ketene	9.61	Methyl mercaptan	9.44
Hydrazine	8.10	**L**		Methyl methacrylate	9.70
Hydrogen	15.43	2,3-Lutidine	8.85	Methyl propionate	10.15
Hydrogen bromide	11.62	2,4-Lutidine	8.85	Methyl propyl ketone	9.39
Hydrogen chloride	12.74	2,6-Lutidine	8.85	a-Methyl styrene	8.35
Hydrogen cyanide	13.91	**M**		Methyl thiocyanate	10.07
Hydrogen fluoride	15.77	2-Methyl furan	8.39	Methylal (dimethoxymethane)	10.00
Hydrogen iodide	10.38	2-Methyl napthalene	7.96	Methylcyclohexane	9.85
Hydrogen selenide	9.88	1-Methyl napthalene	7.96	Methylene chloride	11.32
Hydrogen sulfide	10.46	2-Methyl propene	9.23	Methyl-n-amyl ketone	9.30
Hydrogen telluride	9.14	2-Methyl-1-butene	9.12	Monomethyl aniline	7.32
Hydroquinone	7.95	2-Methylpentane	10.12	Monomethyl hydrazine	7.67
I		3-Methyl-1-butene	9.51	Morpholine	8.20
1-Iodo-2-methylpropane	9.18	3-Methyl-2-butene	8.67	n-Methyl acetamide	8.90
1-Iodobutane	9.21	3-Methylpentane	10.08	**N**	
1-Iodopentane	9.19	4-Methylcyclohexene	8.91	1-Nitropropane	10.88
1-Iodopropane	9.26	Maleic anhydride	10.80	2-Nitropropane	10.71
2-Iodobutane	9.09	Mesityl oxide	9.08	Naphthalene	8.12
2-Iodopropane	9.17	Mesitylene	8.40	Nickel carbonyl	8.27
Iodine	9.28	Methane	12.98	Nitric oxide, (NO)	9.25
Iodobenzene	8.73	Methanethiol (methyl mercaptan)	9.44	Nitrobenzene	9.92
Isobutane	10.57	Methyl acetate	10.27	Nitroethane	10.88
Isobutyl acetate	9.97	Methyl acetylene	10.37	Nitrogen	15.58
Isobutyl alcohol	10.12	Methyl acrylate	9.90	Nitrogen dioxide	9.78
Isobutyl amine	8.70	Methyl alcohol	10.85	Nitrogen trifluoride	12.97
Isobutyl formate	10.46	Methyl amine	8.97	Nitromethane	11.08
Isobutyraldehyde	9.74	Methyl bromide	10.54	Nitrotoluene	9.45

Chemical	IP (eV)	Chemical	IP (eV)	Chemical	IP (eV)
p-Nitrochloro benzene	9.96	Propylene dichloride	10.87	**V**	
O		Propylene imine	9.00	o-Vinyl toluene	8.20
Octane	9.82	Propylene oxide	10.22	Valeraldehyde	9.82
Oxygen	12.08	Propyne	10.36	Valeric acid	10.12
Ozone	12.08	Pyridine	9.32	Vinyl acetate	9.19
P		Pyrrole	8.20	Vinyl bromide	9.80
1-Pentene	9.50	**Q**		Vinyl chloride	10.00
1-Propanethiol	9.20	Quinone	10.04	Vinyl methyl ether	8.93
2,4-Pentanedione	8.87	**S**		**W**	
2-Pentanone	9.38	Stibine	9.51	Water	12.59
2-Picoline	9.02	Styrene	8.47	**X**	
3-Picoline	9.02	Sulfur dioxide	12.30	2,4-Xylidine	7.65
4-Picoline	9.04	Sulfur hexafluoride	15.33	m-Xylene	8.56
n-Propyl nitrate	11.07	Sulfur monochloride	9.66	o-Xylene	8.56
Pentaborane	10.40	Sulfuryl fluoride	13.00	p-Xylene	8.45
Pentane	10.35	**T**			
Perchloroethylene	9.32	o-Terphenyls	7.78		
Pheneloic	8.18	1,1,2,2-Tetrachloro-1,2-difluoroethane (Freon 112)	11.30		
Phenol	8.50	1,1,1-Trichloroethane	11.00		
Phenyl ether (diphenyl oxide)	8.82	1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	11.78		
Phenyl hydrazine	7.64	2,2,4-Trimethyl pentane	9.86		
Phenyl isocyanate	8.77	o-Toluidine	7.44		
Phenyl isothiocyanate	8.52	Tetrachloroethane	11.62		
Phenylene diamine	6.89	Tetrachloroethene	9.32		
Phosgene	11.77	Tetrachloromethane	11.47		
Phosphine	9.87	Tetrahydrofuran	9.54		
Phosphorus trichloride	9.91	Tetrahydropyran	9.25		
Phthalic anhydride	10.00	Thiolacetic acid	10.00		
Propane	11.07	Thiophene	8.86		
Propargyl alcohol	10.51	Toluene	8.82		
Propiolactone	9.70	Tribromoethene	9.27		
Propionaldehyde	9.98	Tribromofluoromethane	10.67		
Propionic acid	10.24	Tribromomethane	10.51		
Propionitrile	11.84	Trichloroethene	9.45		
Propyl acetate	10.04	Trichloroethylene	9.47		
Propyl alcohol	10.20	Trichlorofluoromethane (Freon 11)	11.77		
Propyl amine	8.78	Trichloromethane	11.42		
Propyl benzene	8.72	Triethylamine	7.50		
Propyl ether	9.27	Trifluoromonobromo-methane	11.40		
Propyl formate	10.54	Trimethyl amine	7.82		
Propylene	9.73	Tripropyl amine	7.23		

Appendix C
Response Factor Multipliers[1]

Chemical	PID			FID			
	10 ppm	100 ppm	1000 ppm	10 ppm	100 ppm	1000 ppm	10000 ppm
Acetic acid	7.021	7.026	7.076	2.071	2.062	1.974	1.093
Acetone	1.342	1.417	2.174	0.901	0.899	0.884	0.728
Acetonitrile	—	—	—	1.134	1.134	1.129	1.086
Acrylic acid	11.308	11.330	11.558	6.557	6.510	6.044	—
Allyl alcohol	2.723	2.825	3.845	1.193	1.187	1.133	0.589
Ammonia	21.666	21.725	22.319	—	—	—	—
Amyl alcohol	5.424	5.696	8.419	0.692	0.686	0.632	—
Benzene	0.702	0.751	1.239	0.346	0.344	0.323	0.121
Benzyl chloride	0.743	0.811	1.492	0.472	0.481	0.571	—
1,3-Butadiene	0.773	0.832	1.428	0.758	0.754	0.706	0.227
n-Butane	1.555	1.617	2.238	0.583	0.580	0.552	0.267
1-Butanol	7.408	7.590	9.401	0.835	0.831	0.786	—
2-Butanone	1.075	1.149	1.893	0.680	0.678	0.660	0.475
1-Butene	1.438	1.505	2.173	0.750	0.745	0.700	0.249
Butyl acetate	3.732	3.930	5.902	0.508	0.506	0.484	0.266
Butyl acrylate	2.843	3.022	4.808	0.591	0.587	0.549	—
Carbon disulfide	1.285	1.351	2.015	—	—	—	—
CFC-12	—	—	—	4.157	4.170	4.309	5.696
CFC-113	—	—	—	0.717	0.717	0.720	0.748
Chlorobenzene	0.513	0.564	1.074	0.347	0.345	0.326	0.137
Chloroform	4.838	4.909	5.612	2.229	2.241	2.356	3.510
2-Chlorotoluene	0.580	0.641	1.256	0.417	0.414	0.387	—
m-Cresol	8.399	6.941	—	3.708	4.816	—	—
Cyclohexane	1.875	1.970	2.920	0.467	0.463	0.430	0.094
n-Decane	2.201	2.312	3.415	0.420	0.413	0.333	—
Dimethylformamide	0.936	1.035	2.023	1.710	1.707	1.684	—
Ethane	27.069	27.906	36.275	0.895	0.892	0.869	0.635
Ethanol	5.303	5.383	6.180	1.644	1.641	1.606	1.264
2-Ethoxyethanol	1.992	2.150	3.721	1.315	1.309	1.246	—
Ethylbenzene	0.675	0.732	1.306	0.341	0.339	0.317	0.101
Ethyl acetate	6.639	6.831	8.757	0.799	0.798	0.779	0.592
Ethyl acrylate	4.628	4.818	6.716	0.758	0.755	0.724	0.417
Ethyl lactate	4.867	5.020	6.544	0.984	0.962	0.741	—
Ethylene	5.715	5.804	6.690	1.337	1.331	1.277	0.736
Ethylene oxide	4.986	5.080	6.025	1.294	1.293	1.287	1.222
Formaldehyde	1.169	1.065	—	7.286	7.740	—	—
n-Heptane	4.074	4.258	6.094	0.390	0.388	0.363	0.114
n-Hexane	6.434	6.683	9.167	0.426	0.424	0.397	0.126
Iodomethane	0.231	0.275	0.714	3.014	3.002	2.887	1.731
Isobutanol	7.867	8.018	9.526	0.960	0.954	0.892	0.274

[1]Thermo Environmental Instruments. TVA 1000 response factors. 2000. P/N 50039.

Chemical	PID			FID			
	10 ppm	**100 ppm**	**1000 ppm**	**10 ppm**	**100 ppm**	**1000 ppm**	**10000 ppm**
Isobutylene	1.000	1.000	1.795	0.663	0.659	0.620	0.238
Isopropyl alcohol	9.555	9.811	12.371	0.950	0.948	0.924	0.690
Isopropyl ether	0.939	1.020	1.834	0.449	0.447	0.425	0.205
Methanol	5.265	5.351	6.211	3.815	3.813	3.796	3.622
Methyl chloride	0.728	0.747	0.941	0.997	0.998	1.012	1.156
Methylcyclohexane	1.094	1.182	2.068	0.389	0.386	0.358	0.075
Methylene chloride	2.001	2.057	2.614	1.142	1.147	1.197	1.700
MIBK	0.921	1.014	1.944	0.452	0.455	0.477	—
MTBE	1.055	1.134	1.921	0.576	0.574	0.551	0.323
n-Nonane	2.404	2.536	3.861	0.367	0.364	0.329	—
n-Octane	2.883	3.051	4.734	0.351	0.349	0.323	0.071
n-Pentane	1.068	1.132	1.770	0.505	0.502	0.474	0.186
PGME	1.650	1.745	2.695	0.844	0.842	0.828	—
PGMEA	1.141	1.236	2.191	0.502	0.510	0.588	—
Propane	—	—	—	0.623	0.622	0.603	0.418
Propylene	1.359	1.428	2.113	0.957	0.952	0.903	0.413
Styrene	0.523	0.577	1.114	0.362	0.360	0.345	0.188
Tetrachloroethylene	0.738	0.795	1.361	0.974	0.972	0.961	0.843
1,1,1,2-Tetrafluoroethane	—	—	—	0.302	0.302	0.303	0.312
Tetrahydrofuran	3.400	3.489	4.375	1.180	1.179	1.166	1.040
Toluene	0.644	0.696	1.217	0.339	0.337	0.317	0.114
Trichloroethylene	0.605	0.674	1.363	1.156	1.152	1.113	0.719
Triethylamine	0.825	0.894	—	0.385	0.383	0.365	0.179
Vinyl acetate	1.377	1.461	2.297	1.102	1.098	1.059	0.669
Vinyl chloride	2.334	2.428	3.360	1.253	1.248	1.195	0.661
Vinylidene fluoride	23.387	23.485	24.473	1.157	1.153	1.110	0.678
Xylenes	0.605	0.662	1.236	0.319	0.317	0.298	0.104

LIST OF ABBREVIATIONS AND ACRONYMS

CWA	chemical warfare agents
ESOH	Environmental Safety and Occupational Health
FID	flame ionization detector
IP	ionization potential
PID	photoionization detector
ppb	parts per billion
ppm	parts per million
TVA	toxic vapor analyzer
USAFSAM	United States Air Force School of Aerospace Medicine